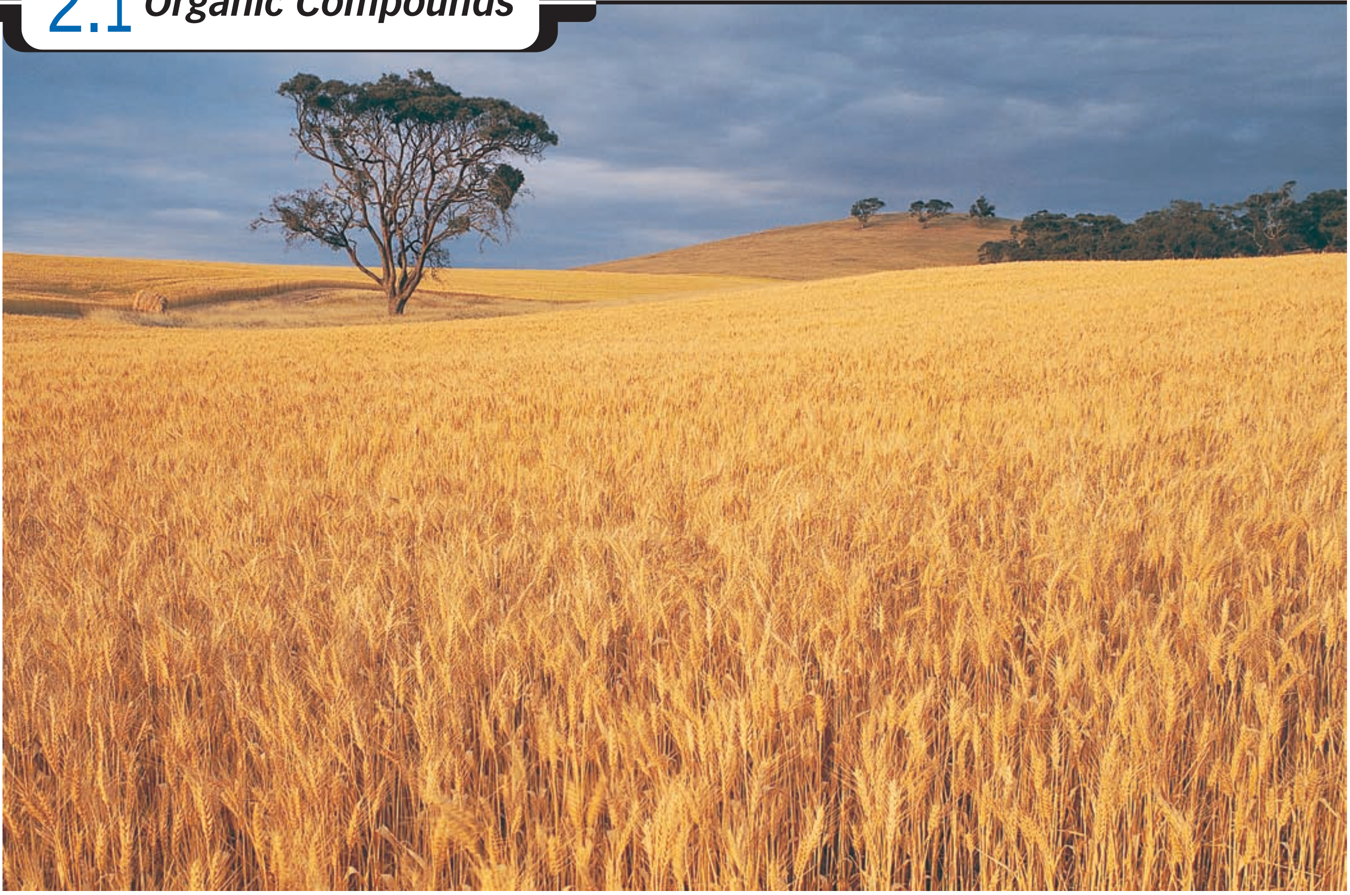
2.1 Organic Compounds



Successful farming relies on more than selecting an appropriate crop to match soil conditions. Over the length of a growing season, farmers manage many factors that affect the health and growth of crop plants. Farming requires careful observation of the crop during key stages in its growth. Many farmers use fertilizers, herbicides, and pesticides at certain times of the growing season in hopes of producing a large, high-quality crop.

As many people in the agriculture industry will tell you, current farming practices that include the use of organic compounds are necessary for crop production. Scientific evidence collected from water and from the tissues of animals suggests that the use of organic compounds in farming and in manufactured materials may have an impact far beyond what they were originally intended for.

In this lesson you will study some of the substances used in agriculture and around your home, along with their intended and unintended effects. You will also examine how the chemical properties of organic compounds influence their behaviour in the environment.

Figure B2.1: Fat samples taken from a polar bear can be used to detect presence of organic pollutants within arctic ecosystems.

Organic Compounds

In Science 20 you were introduced to organic chemistry—the study of compounds composed of carbon. The simplest types of organic molecules are hydrocarbons. The bonding between the carbon atoms in a hydrocarbon is significant. As demonstrated in Figure B2.2, a single, double, or even triple bond can exist between carbon atoms in a hydrocarbon.

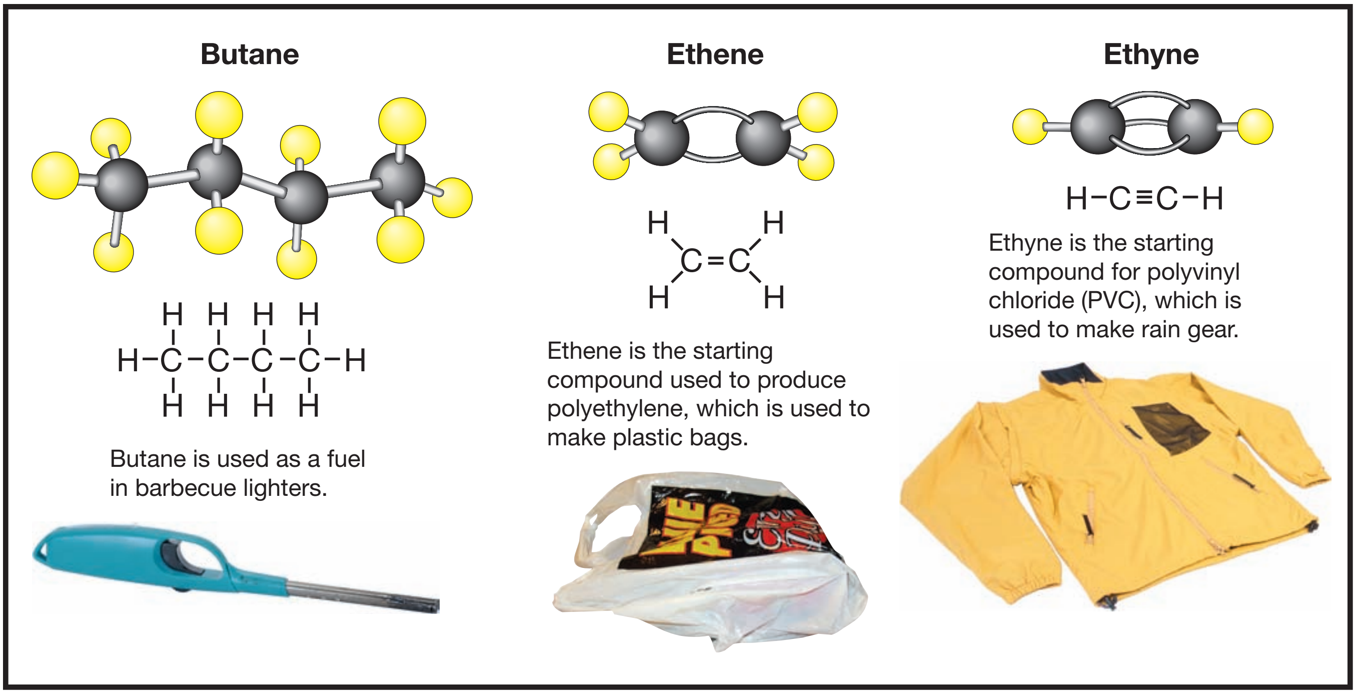


Figure B2.2: Hydrocarbons are the simplest types of organic molecules.

You may recall that hydrocarbons with multiple bonds between carbon atoms are unsaturated and have a different name than saturated hydrocarbons. You will review the naming of hydrocarbons later in this lesson; but for now, use the next activity to review some of the concepts about the shape and other features of hydrocarbons.

Try This Activity

Building Models of Hydrocarbons

Science Skills
✓ Analyzing and Interpreting

Purpose

You will construct a molecular model for each hydrocarbon listed.

Background Information

Molecular models can be used to provide accurate information about the shape of the molecule and the types of bonds between carbon atoms in a hydrocarbon molecule.

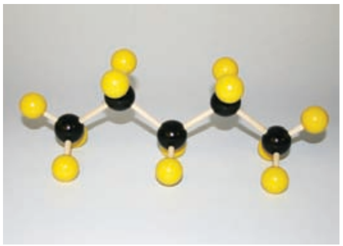
Materials

- molecular model kit

Procedure

Build a model of each compound listed in question 1. Use your model kit to determine whether there are enough hydrogen atoms in the chemical formula to fill the spaces around each carbon atom. Use an additional spring to fill open spaces between carbon atoms to symbolize double bonds where necessary. Use only single or double bonds between carbon atoms when constructing models in this activity.

1. Copy and complete the following table. For each molecule you build, record information about the molecule.

Chemical Formula	Complete Structural Diagram	Bonds Between Carbon Atoms	Saturated or Unsaturated
C_5H_{12}		all single bonds no double bonds	saturated
C_5H_{10}			
C_5H_8			
C_6H_{14}			
C_6H_{12}			
C_6H_{10}			
C_6H_8			
C_6H_6			
C_6H_6 (circular)			
C_7H_8 (circular)			
C_8H_{10} (circular)			

Analysis

2. In Science 20 you learned that the general structure for hydrocarbon molecules was linear. Is this a correct description of the general shape for all hydrocarbons? Describe other arrangements that are possible.
3. If you reduce the number of hydrogens, describe the effect on the arrangement of carbons within a hydrocarbon.
4. Is it possible to have a saturated hydrocarbon that does not possess the maximum number of hydrogen atoms?

Naming System for Hydrocarbons

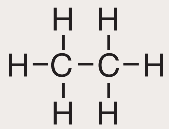
If you compare the molecules you constructed with those built by other students, you may notice that there are many possible correct formations. In order to communicate the precise arrangement of the atoms within organic molecules, a systematic naming system is used. Recall that the longest continuous chain of carbon atoms is considered to be the backbone for most organic molecules and features prominently in the name.

To review the systematic names for linear and branched hydrocarbon molecules, refer to the “Naming Hydrocarbons—Flowchart” handout from the Science 30 Textbook CD.

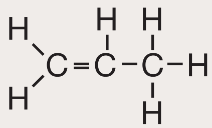
Practice

1. Write the systematic names for the following hydrocarbon compounds.

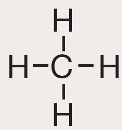
a.



b.



c.



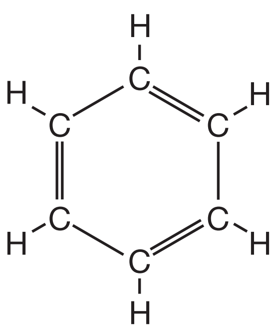
2. Draw the structural diagram for each compound given.

a. 2,2-dimethylpropane

b. 2-methylprop-1-ene

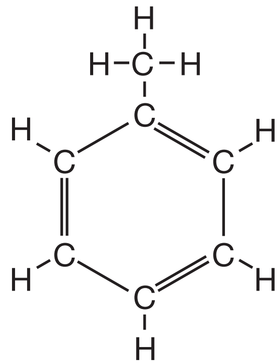
Hydrocarbons can come in many arrangements, including cyclic shapes. One arrangement for the carbon atoms is a hexagon, and one type of hexagonal hydrocarbon structure is a **benzene ring**. Benzene, C_6H_6, and other molecules containing this ring structure are a group of compounds that share similar physical and chemical properties that make them unique organic compounds. This structure can also be referred to as an **aromatic ring** or **phenyl ring**. Aromatic compounds, biphenyls, or benzene-based compounds that you may hear about in the news are all substances that contain this hexagonal structure.

Benzene



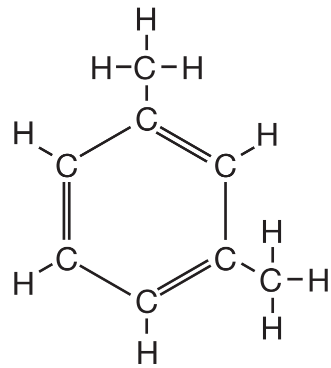
- found in gasoline
- used to make polystyrene

Toluene



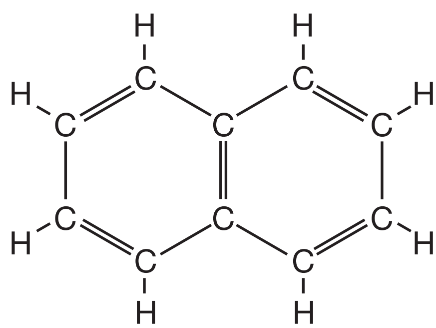
- found in high-octane gasoline
- used in glues for plastic

Xylene



- found in high-octane gasoline
- used in rubber cement

Napthalene



- found in water
- used as moth repellent and fungicide

benzene ring: the hexagonal-ring-shaped chemical structure formed by six carbon atoms and six hydrogen atoms or other atoms

aromatic ring: another name for a benzene ring

phenyl ring: another name for a benzene ring

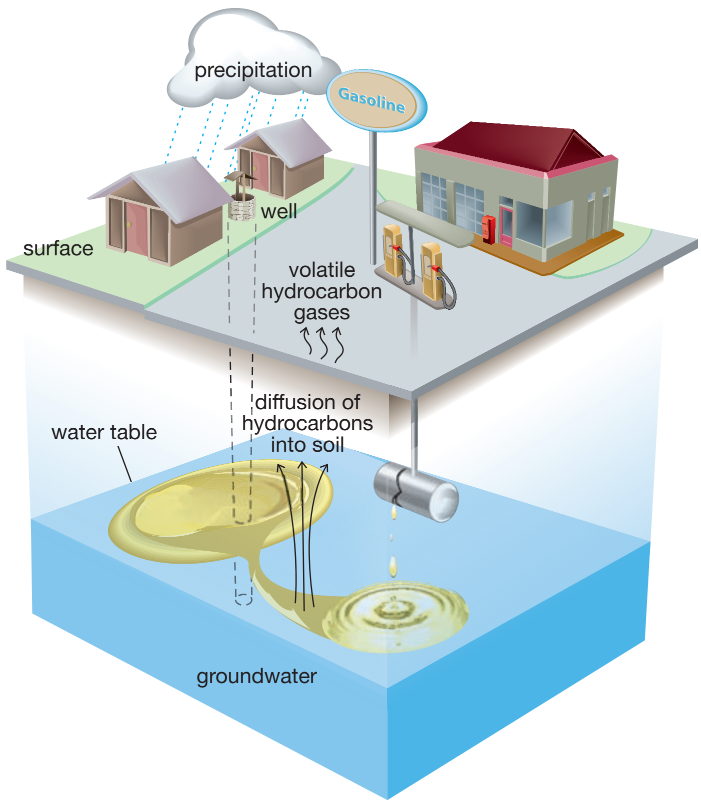
Benzene and Its Consequences

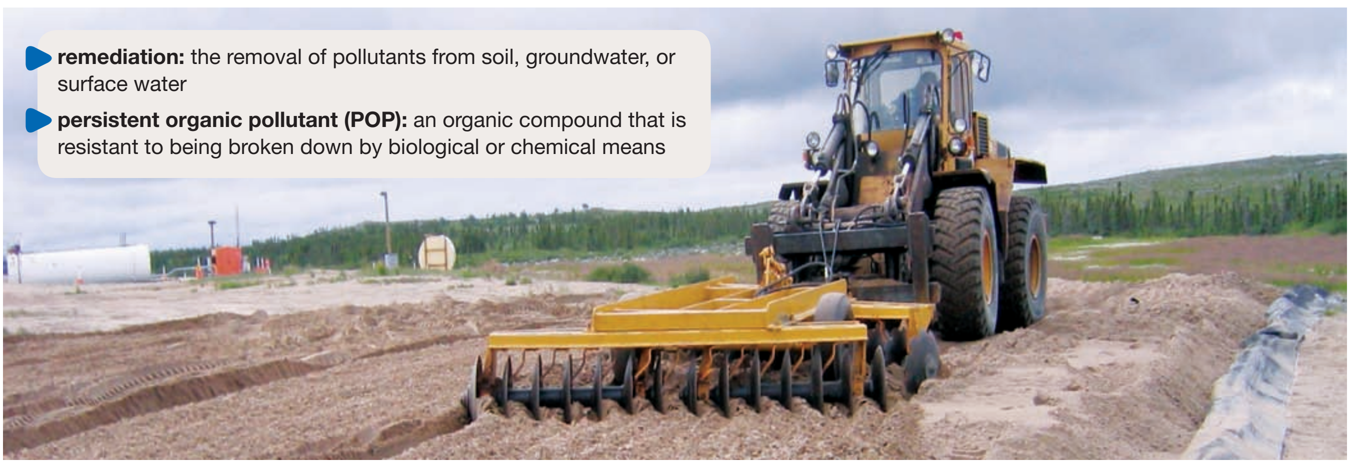
Aromatic compounds are naturally occurring compounds, present in natural resources like petroleum and coal. The gasoline or diesel fuel used in automobiles is a mixture of many hydrocarbons, including aromatic compounds. At one time, benzene and related aromatic compounds made up a large percentage of the hydrocarbons in gasoline. When scientific evidence first suggested that benzene was a carcinogen, action was taken by government and industry to reduce the concentration of benzene in gasoline. Legislation in Canada restricts the percentage of benzene permitted in gasoline.

Cleaning up gasoline that has leaked from an underground storage tank or cleaning up a fuel spill requires the removal of the contaminated soil from the site for treatment. Even though the densities of hydrocarbons are less than the density of water, some compounds in petroleum and gasoline are soluble in water. At spill sites there is often concern about the leaching of benzene and other aromatic hydrocarbons into sources of drinking water. This leaching can contaminate well water and ground water, threatening the health of animals and humans. Water-quality tests performed on well water and other sources of drinking water can identify whether any hydrocarbons are present (e.g., benzene).

The contaminated soil removed from a service station must be treated by a process called **remediation**. Remediation involves the removal or breakdown of hydrocarbons in the spilled gasoline. During remediation, linear hydrocarbons tend to be quickly broken down by the action of bacteria in the soil. Unfortunately, the remediation of molecules containing benzene rings is not as quickly achieved. As you learned earlier, the chemical stability of the benzene rings makes it more difficult for bacteria or chemical processes to break them down. The chemical stability of benzene-based molecules has resulted in their classification as persistent organic molecules, or **persistent organic pollutants** (POPs).

Figure B2.3: Service stations sometimes have to replace their underground fuel tanks with new tanks to keep hydrocarbons in gasoline from leaching into soil because of corroded containers.





remediation: the removal of pollutants from soil, groundwater, or surface water

persistent organic pollutant (POP): an organic compound that is resistant to being broken down by biological or chemical means

You may recall that the presence of double bonds can influence a molecule’s shape and chemical reactivity. If the benzene ring consists of three double bonds, you would expect that aromatic compounds would be very reactive, like unsaturated hydrocarbons. Despite the prediction that three double bonds are present in a benzene molecule, substances containing benzene rings are very stable unlike saturated hydrocarbons. Analysis of the structure of the benzene ring demonstrates that bonds between carbon atoms that form the ring are not similar to the double bonds between the carbon atoms in other hydrocarbons. Aromatic compounds have a reactivity similar to compounds with single bonds, but do not have a structure like those with single bonds.

Structural Diagrams of Benzene C_6H_6

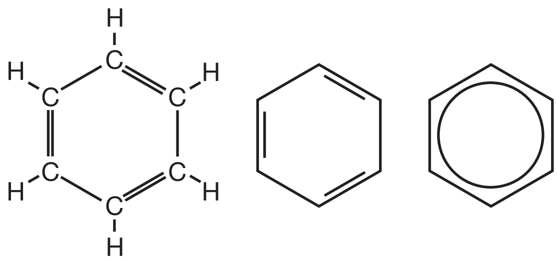


Figure B2.4: Aromatic rings are represented using alternating single and double bonds or using a circle inside the ring to represent resonance.

Carbons in a benzene ring demonstrate a unique bonding arrangement called **resonance**. Within an aromatic ring, extra electrons become shared by all the carbon atoms. A circle placed inside the hexagon in the structural diagram indicates this special bonding in the benzene ring. This unique bonding is believed to be responsible for the high degree of chemical stability and the flat shape of the benzene ring structure.

resonance: a concept used to describe the true structure for certain compounds that cannot be accurately represented using any one type of bonding structure

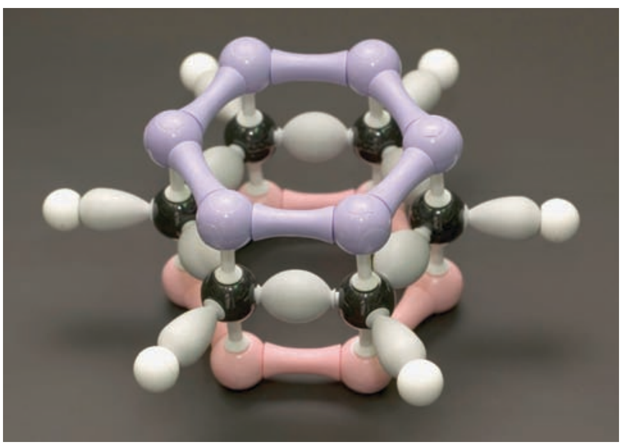


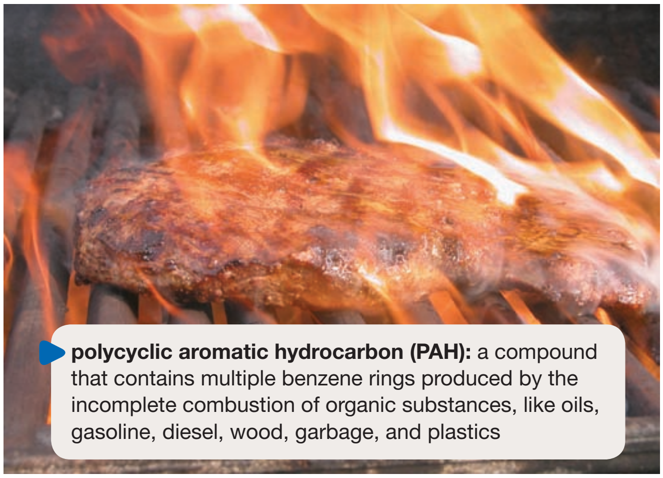
Figure B2.5: The purple and pink rings above and below this model for benzene represent the bonding of the six carbon atoms in the ring to the extra electrons.

The temperature at which combustion occurs in motor vehicles is not sufficient to break apart the aromatic compounds in the fuel. Concern about the presence of benzene in tailpipe emissions was a major factor in the development of legislation to reduce the concentration of aromatic hydrocarbons in gasoline.

Practice

3. Draw three diagrams used to represent a benzene ring.

4. Write two names, other than benzene, that describe the chemical structures in question 3.



polycyclic aromatic hydrocarbon (PAH): a compound that contains multiple benzene rings produced by the incomplete combustion of organic substances, like oils, gasoline, diesel, wood, garbage, and plastics

Figure B2.6: High grill temperatures and flames are used to charbroil foods.

Many people love the taste of charbroiled foods, but the incomplete combustion of oils from the food can produce **polycyclic aromatic hydrocarbons** (**PAHs**). Like the particles that form the charred layer on a steak, PAHs are particulate emissions contained in motor vehicle exhaust or the smoke from forest fires. Recent research has indicated that polycyclic aromatic hydrocarbons, like benzopyrene, have the ability to interact with deoxyribonucleic acid (DNA) and form structures that may result in mutations. Because emissions from diesel automobiles are a major source of PAH emissions, many major cities are investigating means to reduce particulate emissions from diesel engines, including those in cars, buses, and trucks. When you cook food using a barbecue, you may want to use a low-temperature grill to reduce flare-ups and the PAHs present in your food.

Chemical Structure of Benzopyrene

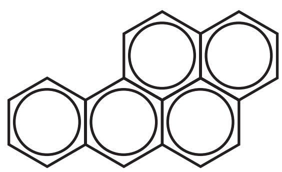


Figure B2.7: Benzopyrene is an example of a polycyclic aromatic hydrocarbon.

Practice

5. The City of Edmonton tested filters on diesel-powered buses to determine whether they were able to reduce particulate-matter emissions.

a. Use the Internet or other sources to identify the characteristic used to classify particulate-matter emissions.

b. Prepare a table that identifies the two groups of particulate-matter emissions and their sources. Include two examples of processes that produce each type of particulate-matter emission.

6. Obtain the handout "Diesel Particulate Filter (DPF) Demonstration" from the Science 30 Textbook CD. Read the handout, and answer the questions that follow.

a. State the problem being investigated by this study.

b. What do you think the term *local environmental conditions* refers to? Why is this such an important consideration?

c. List the controlled variables used in the study.

7. Gasoline is a mixture of many hydrocarbons. A few of the many components found in gasoline are listed in a table in the "Some Components of Gasoline" handout on the Science 30 Textbook CD. Use the Internet to find the chemical formula and chemical structure for the components listed. Identify which of the substances in the list are alkanes, alkenes, aromatic compounds, hydrocarbons, and organic compounds.

DID YOU KNOW?

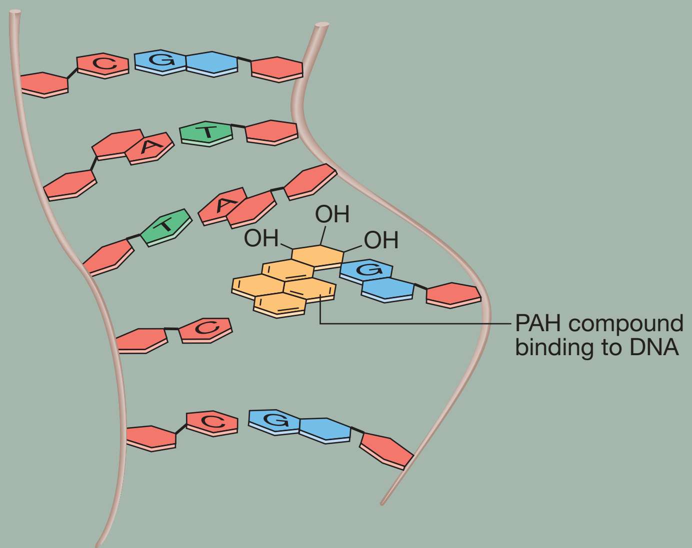
Many naturally occurring compounds, like tobacco, contain molecules with benzene rings. The low-temperature combustion of tobacco that occurs while smoking produces carcinogens that include benzene, C_6H_6, and a PAH called benzo(c)phenanthrene.

DID YOU KNOW?

You have a greater likelihood of being exposed to benzene inside your home than outdoors. Glues, paints, and solvents are common sources. Benzene is also present in tobacco smoke and vehicle exhaust.

Science Links

The three-dimensional shape of the benzene ring is similar to the shape of some parts of the DNA molecule. The ability of PAH and other molecules to form bonds to the nitrogen bases in a DNA molecule may result in the development of mutations. The structure of DNA and mutations and their effect on cells are covered in more detail in Unit A.



Science Links

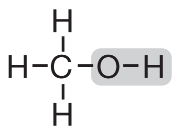
Exposure to benzene can affect the production of red and white blood cells. The role of cells within blood is covered extensively in Unit A.

Functional Groups

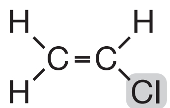
The petrochemical industry in Alberta involves other processes in addition to the extraction of oil and natural gas. Hydrocarbons, as you may recall, can be used as fuel or as a raw material for the production of plastics or other **synthetic organic molecules** (as shown in Figure B2.8).

synthetic organic molecule: a human-made compound containing carbon

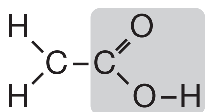
Organic Molecules Containing Functional Groups



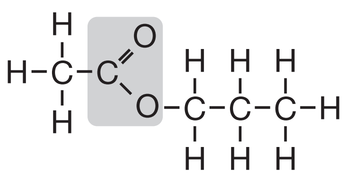
Methanol (wood alcohol)



Vinyl (used for PVC)



Ethanoic Acid (vinegar)



Propyl Ethanoate (aroma of pears)

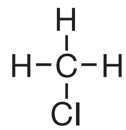
Figure B2.8

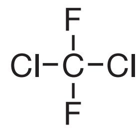
Modifications to naturally occurring hydrocarbons can involve the addition of carbon side chains or the addition of atoms other than carbon or hydrogen, creating organic molecules containing a **functional group**.

Halogenated Hydrocarbons

September 23 is an important day for environmental scientists. It's not a birthday; it is the first day of spring in the southern hemisphere. On this day, the first rays of sunlight illuminate the South Pole, which has been in total darkness throughout its winter. The end of winter is an important time for atmospheric scientists. It provides an opportunity to assess the extent of damage to the layer of ozone in the stratosphere above the South Pole.

Halogenated Hydrocarbons





Chlorofluorocarbons—commonly referred to as CFCs—were invented in the late 1920s to replace ammonia, $NH_3(g)$, sulfur dioxide, $SO_2(g)$, and other gases used in air-conditioning and refrigeration systems. Because CFCs are non-flammable and non-toxic, their use in commercial and residential refrigerators and air-conditioning systems became widespread. Although the worldwide use of CFCs in refrigeration systems and other chemical processes has had many benefits, there is evidence that their use has had harmful consequences for the ozone layer.

chlorofluorocarbon (CFC): a synthetic organic molecule in which hydrogen atoms are replaced with chlorine and fluorine atoms; also called Freon

Figure B2.9: Many CFCs, or Freons, are used in refrigeration systems.

functional group: an arrangement of single atoms or groups of atoms, other than carbon or hydrogen, attached to an organic molecule

Chlorofluorocarbons are part of a larger group of organic molecules called **halogenated hydrocarbons**. Halogenated hydrocarbons are synthetic organic compounds formed by reactions that substitute hydrogen atoms on a hydrocarbon with atoms from the halogen family of elements—chlorine, fluorine, bromine, or iodine. The term *chlorofluorocarbon* (CFC) describes the molecule as having both chlorine and fluorine atoms replacing hydrogen atoms in the chemical structure.

halogenated hydrocarbon: a hydrocarbon molecule that has one or more hydrogen atoms replaced by atoms of chlorine, fluorine, bromine, or iodine

Try This Activity

How Does a Refrigerant Work?

Purpose

You will investigate a physical change of matter and study its potential for use in a refrigeration system.

CAUTION!

Butane is flammable. Perform this activity only under the supervision of a teacher and in a room in which there are no open flames or sparks. Do not open the bags containing the butane unless you are told to do so by your teacher.

Science Skills

✓ Analyzing and Interpreting

Background Information

Butane, C_4H_{10}, has a boiling point of −0.5°C. If compressed, gaseous butane can be converted into its liquid form. In this activity you will observe the energy change that accompanies the change in state as liquid butane becomes gaseous butane.

Materials

- handouts from the Science 30 Textbook CD
  - "Schematic of a Refrigerator"
  - "MSDS: Ammonia"
  - "MSDS: Butane"
- liquid butane (Ask your teacher for this.)
- plastic, zipper-lock sandwich bag
- fume hood
- plastic drywall anchor (#4)
- scissors

Procedure

step 1: Read the entire procedure before starting the experiment. Prepare a suitable data table for recording your observations.

step 2: Read the information on the MSDS for butane. Highlight or underline sections of the MSDS that identify safety concerns regarding the use of butane.

step 3: Obtain a small sample of liquid butane in a zipper-lock sandwich bag from your teacher. Quickly observe how expanded the bag feels and how hot or cold the outside of the bag feels to the touch. Don't record your observations until you have completed step 4.

step 4: Locate where the liquid butane is in the bag. Place your fingers around the outside of the bag in an area where liquid butane is located. Observe the effect the heat from your hand has on the liquid butane and any changes to the amount the bag has expanded. Record your observation to steps 3 and 4 in the data table you prepared earlier.

step 5: Put all the equipment away, and properly dispose of the butane as instructed by your teacher.

Analysis

1. Explain how heat energy from the air surrounding the bag and your hand caused a phase change in the butane. Write the chemical reaction for this change.
2. Explain how the phase change could be used to cool the contents of food placed in a refrigerator.
3. Complete the "Schematic of a Refrigerator" handout by adding the following labels:
   - location of butane in the refrigerator system
   - states of butane at the positions A, B, and C
   - directions of the flow of thermal energy in the coils outside the refrigerator and in the coils inside the refrigerator
4. The compressor motor is an important component of a refrigerator. It forces the gaseous refrigerant to undergo a phase change back into a liquid. Identify the energy change that occurs to the compressed gas when it changes from a gas to a liquid. Explain the function for the coils outside the refrigerator.
5. Compare the safety concerns you identified for butane in step 1 of the procedure to the MSDS provided for ammonia. Based on the information, identify which substance—ammonia or butane—would make a safer refrigerant. Provide a justification for your choice. Identify any additional information you would want to have before making a final choice.

Naming Halogenated Hydrocarbons

The naming system used previously for hydrocarbons can be modified slightly to include hydrogenated hydrocarbons. Halogen atoms present in a molecule are indicated, like hydrocarbons, using the appropriate prefixes. These prefixes are listed in the "Halogen Prefixes" table. The end result will be to name the hydrocarbon part of the molecule first and, then, use prefixes to identify halogen atoms and their location.

HALOGEN PREFIXES

Halogen	Prefix
fluorine	fluoro
chlorine	chloro
iodine	iodo
bromine	bromo

To determine the systematic name for halogenated hydrocarbons, use the method for naming hydrocarbons and add the following steps.

step 1: Name the parent chain.

This is the same as naming the parent chain of a hydrocarbon.

step 2: Find all halogen atoms in the molecule.

You may find it easier if you circle these atoms.

step 3: Determine the appropriate prefixes to represent the halogens.

Each type of halogen atom is referenced using its appropriate prefix. (Refer to the "Halogen Prefixes" table.) If the same halogen atom appears in the molecule more than once, use the same prefixes that indicate the number of branches in a hydrocarbon chain (e.g., *di*- and *tri*-). For example, if two chlorine atoms are present, the prefix is *dichloro*.

step 4: Communicate where each halogen atom appears in the parent chain.

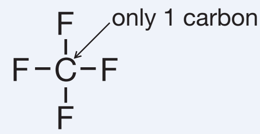
For example, 2-*fluoro* means that there is a fluorine atom on carbon 2 of the parent chain. Also, 2,2-*difluoro* means that there are two fluorine atoms on carbon 2 of the parent chain. If more than one halogen atom appears on the molecule, list them in alphabetical order.

Example Problem 2.1

One of many refrigerants developed by Thomas Midgley was CF_4. Write the systematic name for CF_4.

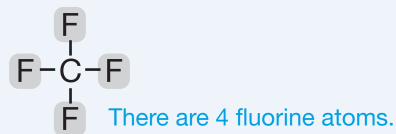
Solution

step 1: Name the parent chain.



The parent chain is methane.

step 2: Find all halogen atoms in the molecule.



step 3: Determine the appropriate prefixes to represent the halogens.

Because there are 4 fluorine atoms, the prefix is *tetrafluoro*-.

step 4: Communicate where each halogen atom appears in the parent chain.

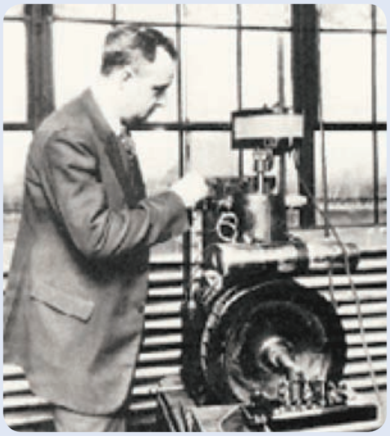
Since there is only 1 carbon in the parent chain, there is no need to communicate where each fluorine atom appears.

Therefore, the systematic name of CF_4 is tetrafluoromethane.

Figure B2.10: Proper maintenance of an air conditioning unit involves checking the refrigerant level.

DID YOU KNOW?

Deaths attributed to leaked refrigerants led Thomas Midgley to develop CFCs. Midgley demonstrated the safety of his discovery to other scientists by inhaling a lung full of the Freon gas and then blowing out a candle flame with the exhaled gas.

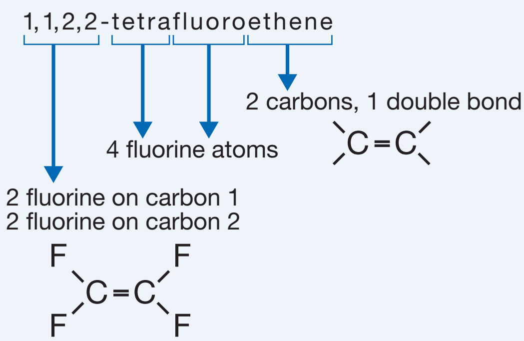


Midgley—a scientist for General Motors Corporation—also worked on developing fuel additives and leaded gasoline.

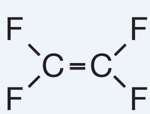
Example Problem 2.2

Teflon—a polymer commonly used on frying pans and valued for its non-stickiness and ability to resist damage from high heat and other chemicals— is produced by the reaction of many molecules of 1,1,2,2-tetrafluoroethene. Draw the molecular structure of a single 1,1,2,2-tetrafluoroethene.

Solution

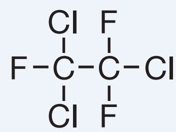


There are no empty bonds to fill with hydrogens. Therefore, the structure of 1,1,2,2-tetrafluoroethene is

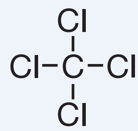


Example Problem 2.3

CFC-113 is a solvent used in the manufacture of computers and electronic components. It is also used in dry cleaning where it replaced the use of CCl_4. Write the systematic names for these two halogenated hydrocarbons.

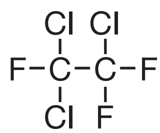
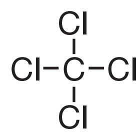


CFC-113



CCl_4

Solution

CFC-113	CCl_4
	
Determine the parent chain.	
ethane	methane
Determine the prefixes.	
trichloro- trifluoro-	tetrachloro-
Show where each halogen appears (if necessary).	
1,1,2-trichloro- 1,2,2-trifluoro-	N/A
Put it all together.	
1,1,2-trichloro-1,2,2-trifluoroethane	tetrachloromethane

Practice

8. The first CFC produced by Thomas Midgley was dichlorodifluoromethane. Draw the chemical structure for this compound.

9. Obtain the “Halogenated Hydrocarbons” handout from the Science 30 Textbook CD. On this handout, you will see some halogenated hydrocarbons listed. Complete this table.

DID YOU KNOW?

The chemical formula for a chlorofluorocarbon (CFC) or a hydrochlorofluorocarbon (HCFC) can be determined from its number.

- Add 90 to the CFC or HCFC number, and write out the resulting number.
- The first number tells you the number of carbon atoms in the molecule.
- The second number tells you the number of hydrogen atoms in the molecule.
- The third number tells you the number of fluorine atoms in the molecule.
- The remaining bonds to the carbon atoms are filled with chlorine atoms.

Example: CFC-11

11 + 90 = 101

1 C 0 H 1 F

A carbon has four bonds, and only one bond is used by fluorine. Therefore, 3 chlorine atoms must be bonded to the carbon atom. The chemical formula is $CFCl_3$.

Use this method to determine the chemical formula for CFC-12, HCFC-22, HCFC-124, and HCFC-134a. Would it be possible to have a CFC-15?

Ozone and Concerns Regarding CFCs

The energy from the Sun is a collection of different forms of radiation. Some of the forms of energy in sunlight include ultraviolet and infrared radiation and visible light. Ultraviolet radiation can cause damage to living tissue because it possesses greater energy than many other forms of radiation found in sunlight. As you have learned, energy from sunlight can excite molecules and initiate chemical reactions in the atmosphere. Oxygen molecules in the **stratosphere** are exposed to ultraviolet radiation, which initiates the development of ozone, $O_3(g)$. The **ozone layer** is a portion of the stratosphere that protects Earth from exposure to excessive levels of ultraviolet radiation. The reactions involving the production and decomposition of ozone that form the ozone cycle absorb the components of ultraviolet radiation—most harmful to human skin and eyes—protecting life on Earth from its harmful effects. The importance of the ozone layer to life on Earth has made it a popular focus for scientific research.

stratosphere: the portion of the atmosphere between 10 km and 50 km above Earth's surface

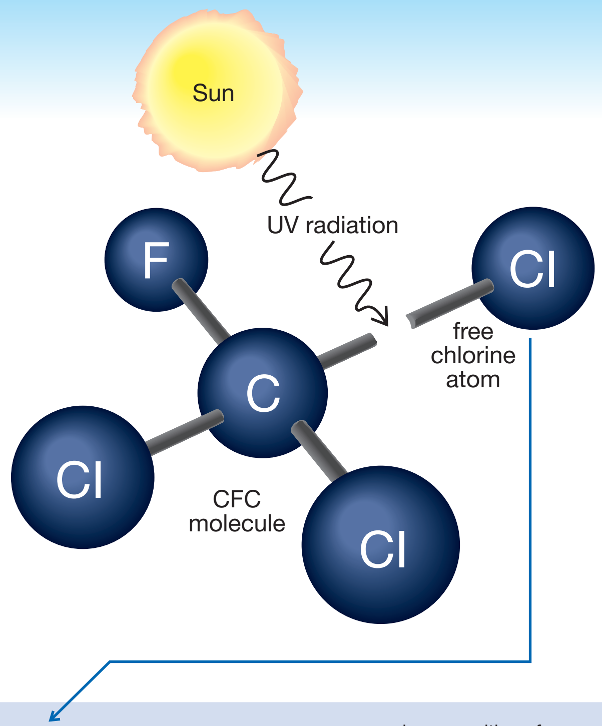
ozone layer: the portion of the stratosphere, where the highest concentrations of ozone occur

Some of the first scientific work on ozone involved identifying the ozone cycle and estimating the quantity of ozone that should be present in the ozone layer. Later—once it became possible to make measurements—it was determined that the actual amount of ozone in the stratosphere was less than the amount predicted. This observation further raised the interest of many scientists who began to work toward identifying a reason for the difference.

Although investigations had shown that some substances reacted with ozone, the demonstration that nitrogen oxides could decompose ozone attracted even more interest toward investigating the effects of human-made emissions on the ozone layer. The role of CFCs in ozone depletion became clearer when key findings from a variety of different research projects studying CFCs and the reactivity of free chlorine atoms were interpreted together.

Evidence had shown that CFCs were stable molecules in the troposphere, where they were exposed to low levels of UV radiation. Once data became available that CFC molecules were present in all levels of the atmosphere, scientists became concerned about the stability of these molecules, since they are exposed to greater levels of UV higher in the stratosphere.

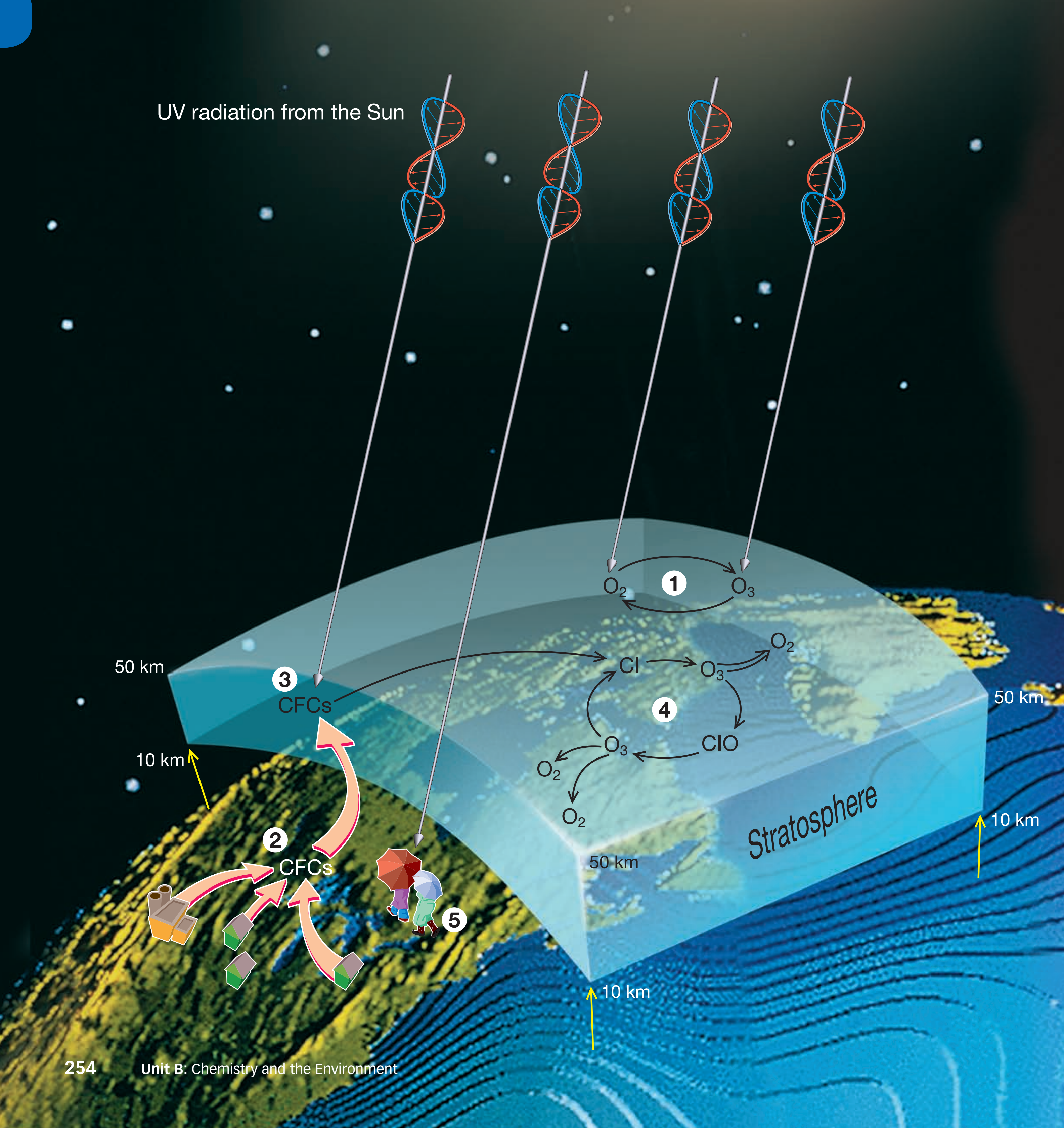
Ozone Depletion Reactions



$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$	decomposition of ozone by free chlorine atom
$O_3(g) + \text{UV radiation} \rightarrow O_2(g) + O(g)$	natural decomposition of ozone (part of ozone cycle)
$O(g) + ClO(g) \rightarrow Cl(g) + O_2(g)$	reaction that re-generates the free chlorine atom

free chlorine atom able to attack more ozone

The Process of Ozone Depletion (simplified)



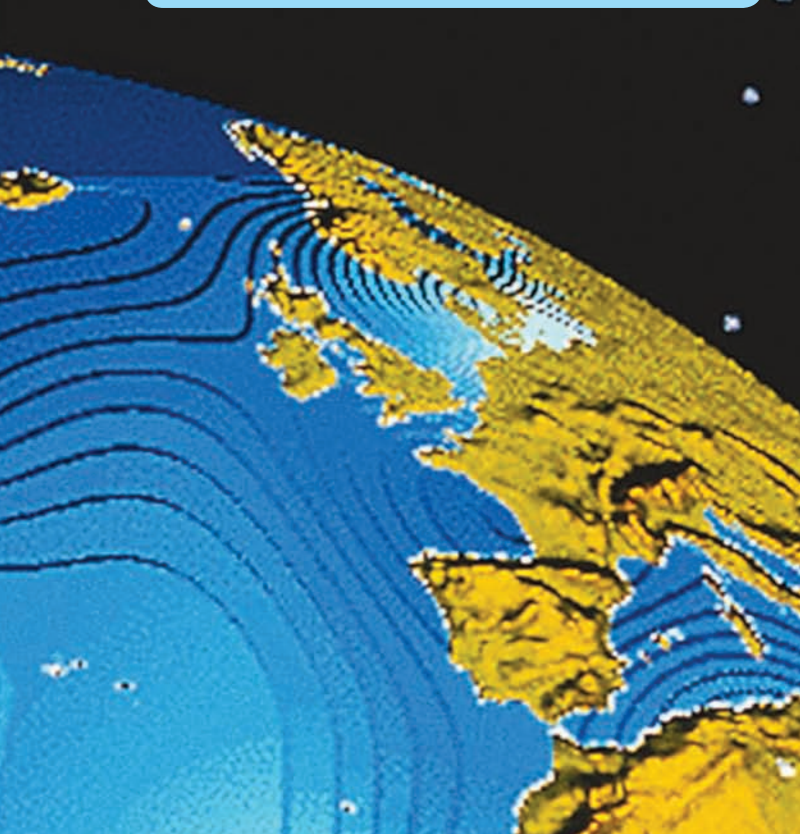
1 **Natural Ozone Cycle:** UV radiation collides with oxygen, $O_2(g)$, and ozone, $O_3(g)$, molecules. Energy from this radiation is absorbed and breaks chemical bonds, creating a cycle. The ozone cycle is the only mechanism to produce stratospheric ozone. Absorption of UV radiation by $O_2(g)$ and $O_3(g)$ prevents harmful forms of radiation from reaching Earth's surface.

2 **CFCs Released:** CFCs are stable below the stratosphere. Winds carry CFCs into the stratosphere.

3 **CFCs Broken Down:** CFCs are exposed to higher levels of UV radiation in the stratosphere. Collisions between CFCs and UV radiation produce chlorine atoms.

4 **Ozone Broken Down:** A reaction between chlorine atoms and ozone occurs. The chlorine atoms are regenerated and attack thousands of ozone molecules. The natural balance in the ozone cycle is disrupted.

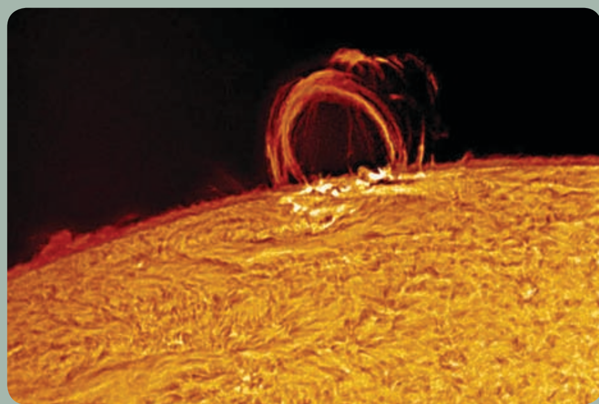
5 **Increased UV at Surface:** Harmful forms of UV can reach Earth's surface because there is less stratospheric ozone.



Results from experiments demonstrated that UV radiation caused the removal of chlorine atoms from CFC molecules in the stratosphere and that the free chlorine atoms could react to destroy ozone. CFCs that were first demonstrated by Midgley as a miracle chemical became an even greater cause for concern when additional evidence demonstrated that chlorine atoms could be regenerated by reactions occurring in the atmosphere. Regeneration provides the opportunity for a single chlorine atom to bring about the destruction of many ozone molecules.

Science Links

Ultraviolet radiation—a form of energy released by the Sun—can produce free radicals in cells, resulting in their damage. Units A and C expand on the intensity and forms of energy released by the Sun, including ultraviolet radiation and its effects on living systems.



DID YOU KNOW?

In 1995—more than 20 years after alerting the world to the impact that CFCs produced by human activity were having on the ozone layer—Paul Crutzen, Mario Molina, and F. Sherwood Rowland won the Nobel Prize in chemistry. Crutzen was acknowledged for his work on the effect of nitrogen oxides on the ozone layer, a crucial discovery that enabled Molina and Rowland to determine that CFCs also destroyed stratospheric ozone. The publication of Molina and Rowland's discovery increased society's attention to environmental issues. Government action in the late 1970s and early 1980s led to restrictions on the use of CFCs as aerosol propellants and resulted in increased attention by government, industry, and scientists toward environmental issues.

Free Radicals

The addition of UV radiation to a CFC can result in the formation of free radicals of chlorine in the atmosphere. You may have heard or read advertisements warning about the effect free radicals can have on your body. You may have heard that free radicals cause aging and can cause damage to parts of the body.

Free radicals are chemical species that have an unpaired electron in their valence shell. You may recall that substances with unpaired electrons seek out other substances they can combine with to fill their valence shell. In the body, exposure to radiation, or substances within food, may result in the production of a variety of oxygen-containing free radicals. Despite their origin, you have seen that free radicals are very reactive and bring about chemical change. Concern about free radicals in people's diet is based on evidence that they can react with lipids (a major component of the cell wall), proteins, and DNA. Damage to any of these components can affect the function of cells and may result in tissue damage.

Vitamin E (α-tocopherol)

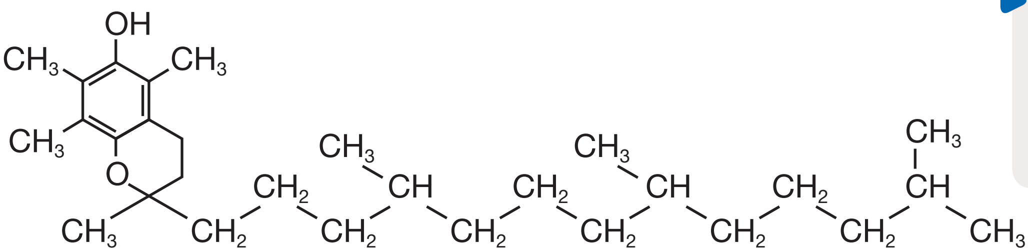


Figure B2.11: Vitamin E

antioxidant: a substance that prevents the oxidation of another substance; a substance present within the body or other materials that reacts with free radicals to protect important components

There is no way to completely avoid free radicals, but it is possible to reduce exposure through food choices containing **antioxidants**. Vitamins E and C, beta-carotene, and lycopene are well-known antioxidants. All of these antioxidants are available from vegetables. If you are concerned about the amount of antioxidants in your diet, consult Canada's Food Guide, a dietician, or other appropriate sources.

Holes in the Ozone Layer

The ozone layer over Earth varies in thickness. The thickness of the ozone layer is measured in Dobson units (DU). One Dobson unit is equivalent to a thickness of 0.01 mm of ozone gas at a standard temperature and pressure (0 °C and 100 kPa). As you can see in Figure B2.12, some regions have significantly higher levels of ozone. Areas with low levels of ozone are called ozone holes.

Total Ozone in Dobson Units (2006/10/24)

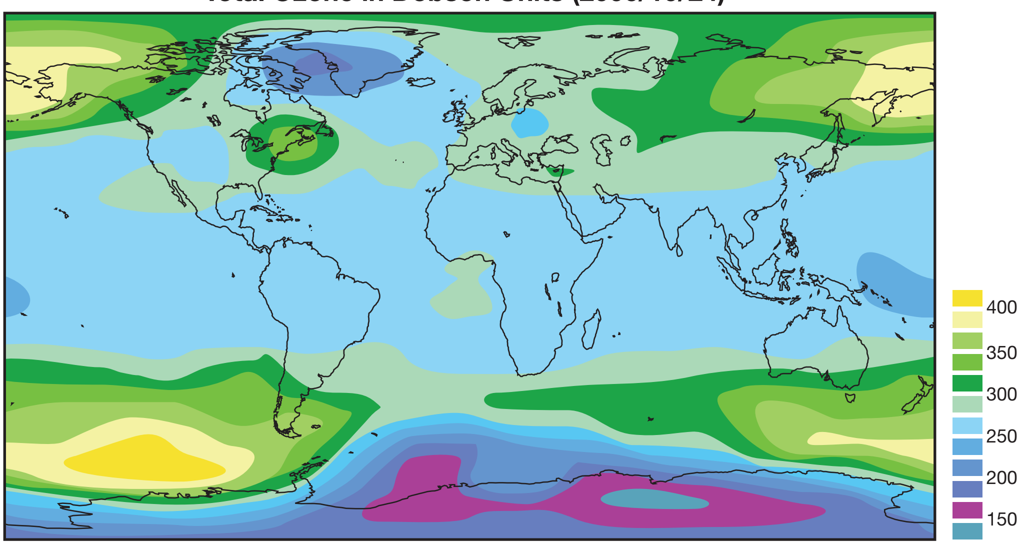


Figure B2.12

The thickness of the ozone layer can be measured daily. One of the most important evaluations of the thickness of the ozone layer occurs at the end of winter. You have learned that the reaction that produces chlorine radicals requires UV radiation. UV radiation is also required for the reaction to produce ozone. Research on the ozone layer tends to focus on the thickness of ozone over Earth's poles. Measurements taken around the end of winter for each hemisphere—September 23 for the South Pole and March 23 for the North Pole—provide scientists with the opportunity to assess the damage done to the ozone layer during the previous year and to compare the data to other years.

Practice

10. The thickness of the ozone layer at an Antarctic research station in 1956 was 321 DU. Calculate the percentage loss in ozone between 1956 and 1997, when the thickness was 139 DU.

11. In Figure B2.12, determine the locations where the thickness of the ozone layer is the lowest.

12. Use the Internet to find a recent world ozone map. Compare this map with Figure B2.13. Identify any similarities and any differences.

13. Graph the following data. Account for the fluctuation in the thickness of the ozone layer during the time for which data is shown.

AVERAGE THICKNESS OF OZONE LAYER OVER ANTARCTICA (2005–2006)

Month	Ozone Thickness (DU)
August	207
September	158
October	155
November	253
December	290
January	298
February	284
March	291
April	278

14. Predict the trend for the average monthly ozone layer thickness over the North Pole over the same time period as shown in question 13.

Monitoring Ozone

The thickness of the ozone layer is determined by data collected both from satellites and from measurements made by devices that travel into the stratosphere by weather balloon. Many satellites use spectrometers and other equipment to measure reflected UV radiation and atmospheric temperatures to determine the amount of ozone.

Balloon measurements use an ozone sonde—a device that draws in ozone as the balloon rises in the atmosphere. The concentration of ozone present at various levels in the atmosphere determines the strength for a radio signal that is sent from the sonde to a detector on the ground.

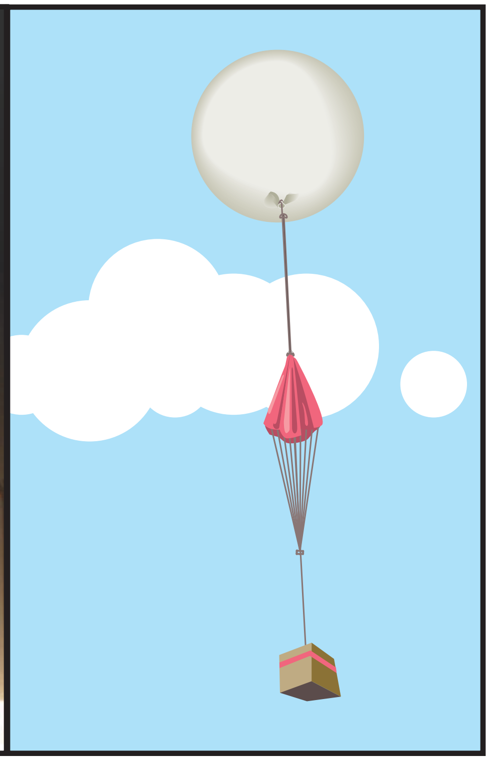


Figure B2.13: The Aura satellite, launched in 2004, is used to monitor the ozone layer.

Practice

15. Use the Internet to determine the names for the abbreviations TOMS and OMI. These devices are used in the measurement of Earth's ozone layer.

16. Measurements of Earth's ozone layer are made using satellites and balloon sondes. Because of the differences between conditions in space and on Earth, different instruments are used. Explain how the use of different instruments to study the ozone layer can improve the interpretation of the data collected.

17. Atmospheric measurements for ozone concentration are expressed as parts per million (ppm), whereas measurements for the free radical chlorine monoxide, $ClO(g)$, are expressed as parts per billion (ppb). Explain the difference between the magnitudes of these two units for concentration. Explain how a change in the concentration of chlorine monoxide in the atmosphere could affect the concentration of ozone.

International Agreements to Protect the Ozone Layer

The scientific evidence that demonstrated the effects of CFCs and other halogenated hydrocarbons on the environment supported the need for action to protect the environment. In 1987, an international treaty called *The Montreal Protocol on Substances That Deplete the Ozone Layer* was developed. Under this agreement, countries commit to phase out the production and use of ozone-depleting substances. As of 2006, the number of countries committing to the Montreal Protocol had grown from its initial group of 40 to 190.

Figure B2.14: Montreal at night

To meet the requirements of the Montreal Protocol, governments are demanding that changes be made to previous practices. In most cases, alternatives to ozone-depleting chemicals must be found or new processes must be developed. Because chlorine atoms (radicals) released from CFCs cause damage to the ozone layer, other halogenated hydrocarbon alternatives to CFCs have been developed. HCFCs (hydrochlorofluorocarbons)—which contain fewer chlorine atoms in their chemical structures—and HFC (hydrofluorocarbons)—which do not contain any chlorine in their chemical structure—cause less damage. Target dates for the reduction of these substances and other ozone-depleting substances are shown in the table.

Ozone-Depleting Substance	Target Date for Elimination Under the Montreal Protocol
Halons	1994
CFCs, HBFCs (hydrobromofluorocarbons), tetrachloromethane	1996
bromomethane	2010
HCFCs	2030

You may wonder whether international agreements like the Montreal Protocol are successful, especially when you see the length of time required for target dates to become effective. Although the process to eliminate ozone-depleting substances appears to take a long time, many people consider the Protocol a success given the large number of countries that have committed to meeting these targets. In some cases, countries have managed to meet target dates ahead of schedule. Reasons that may account for the success of this agreement may include

- a consensus among countries regarding the scientific evidence identifying a threat to the ozone layer by CFCs and other halogenated hydrocarbons
- problem chemicals can be restricted to a few types that can be controlled or for which alternatives can be found
- changes in behaviours regarding the use of ozone-depleting substances that are not costly or do not otherwise affect countries economically

In some cases, even though scientific evidence demonstrates that a compound causes ozone depletion, it is not included in the list of substances to be phased out by the Montreal Protocol. This is because exemptions can be made for substances if there are no alternatives and their use is critical. For example, although scientific evidence has demonstrated that some halogenated hydrocarbons containing bromine have a greater capacity to deplete ozone than CFCs, these substances are not prohibited by the Protocol. Halon-1211 (also known as bromochlorofluoromethane) and Halon-1301 (or bromotrifluoromethane) have a significantly higher ability to deplete ozone when compared to CFCs. Controversy existed at the time the Protocol was drafted because these compounds were used in fire extinguishers in airplanes. Due to the unique conditions and specifications required to contain fires in this environment, few alternatives existed; so to maintain safety, the use of these compounds was allowed under even stricter control. Since then, suitable alternative fire retardants have been found.

DID YOU KNOW?

Canada, the United States, Norway, and Sweden were the first countries to restrict the use of CFCs in aerosol sprays in the late 1970s.

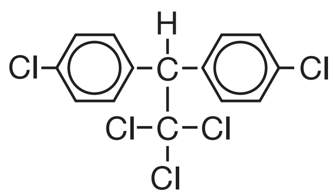
One compound for which a suitable alternative has yet to be found is bromomethane (also called methylbromide). Methylbromide is a pesticide used in agriculture to fumigate soil. A great deal of concern has been expressed by farmers, especially in the United States, that no suitable alternative exists to protect sensitive crops from pests.

In order to demonstrate agreement with the Montreal Protocol, countries applying for critical-use exemptions must justify why they need to continue to produce or import restricted substances.

Other Halogenated Compounds

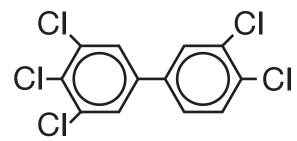
In addition to CFCs, many other synthetic halogenated organic compounds exist. Plastics, fire retardants, paints, solvents, cleaning supplies, pesticides, and herbicides are all examples of the types of products that may contain halogenated hydrocarbons.

Dichlorodiphenyltrichloroethane (DDT)



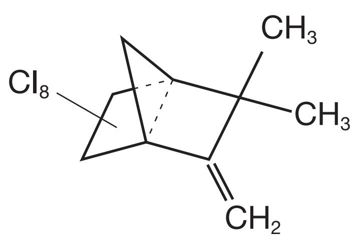
This is used for mosquito control.

Polychlorinated Biphenyl



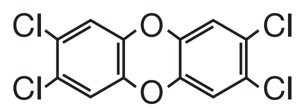
This is used in some older electric transformers.

Toxaphene



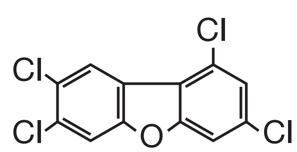
This is a pesticide. **Note:** The exact positions of the chlorine atoms are not known.

Dioxin



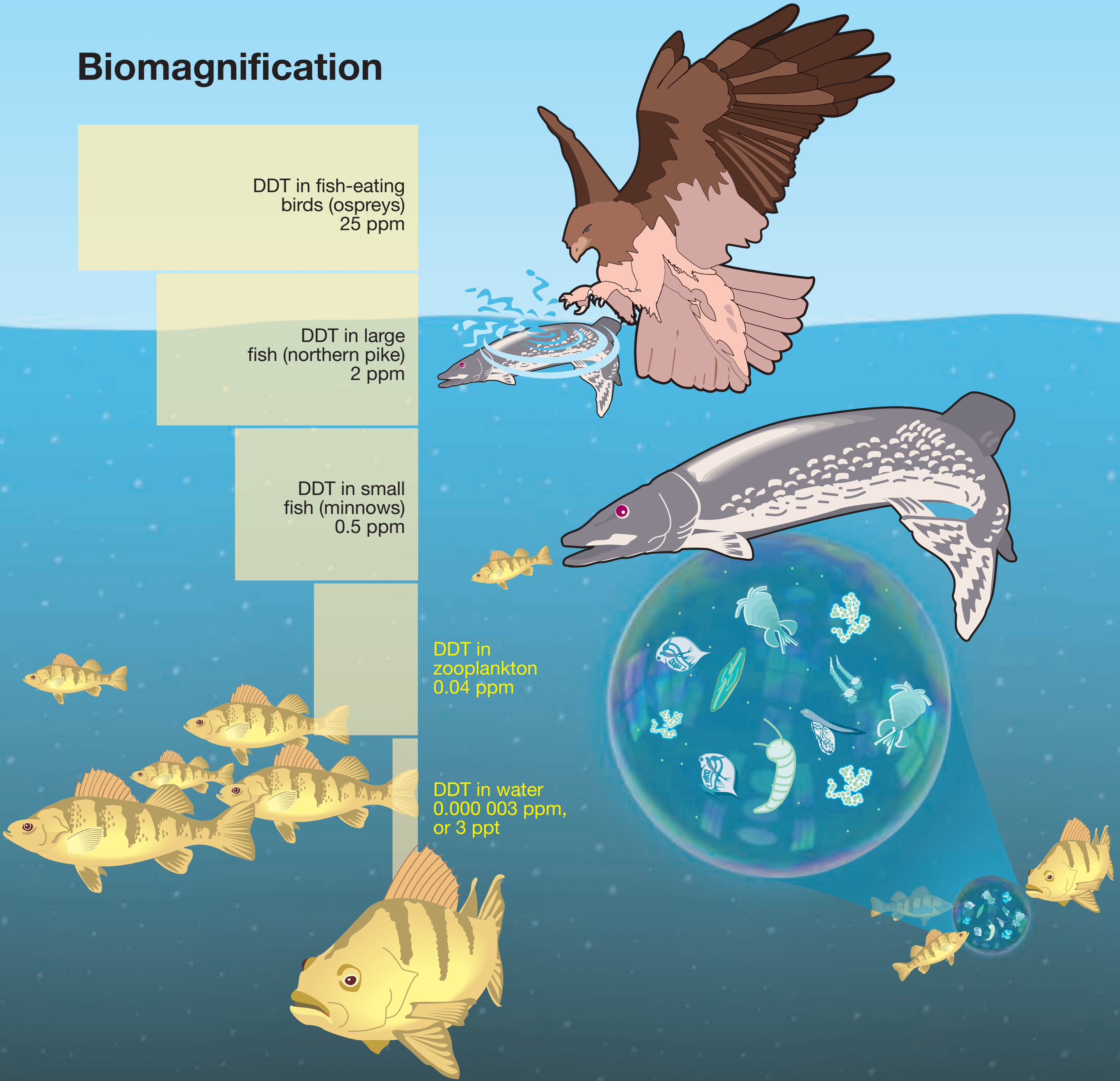
This is a by-product of some chemical processes where chlorine is used.

Furan



This is a by-product of some chemical processes where chlorine is used.

Biomagnification



The only sources of halogenated hydrocarbons are human activities, whether as an intended result or as a by-product. Some, like CFCs and polychlorinated biphenyls (PCBs), were developed for use in a variety of applications because of their chemical stability. However, this characteristic has caused them to be a problem to living organisms. Chlorinated hydrocarbon compounds, like DDT and toxaphene, have been shown to biomagnify precisely because of their tendency not to break down in food chains and affect higher-level organisms within ecosystems, like the peregine falcon, other birds of prey, and humans.

Dioxins and furans are halogenated hydrocarbons produced as a by-product of the chlorine bleaching process for wood pulp and from the low-temperature incineration of chlorinated organic compounds (e.g., plastics). Dioxins, furans, and even pesticides used thousands of kilometres away from the Arctic have been detected in the tissues of organisms in all levels of the arctic food chain, including the breast milk of Inuit women.

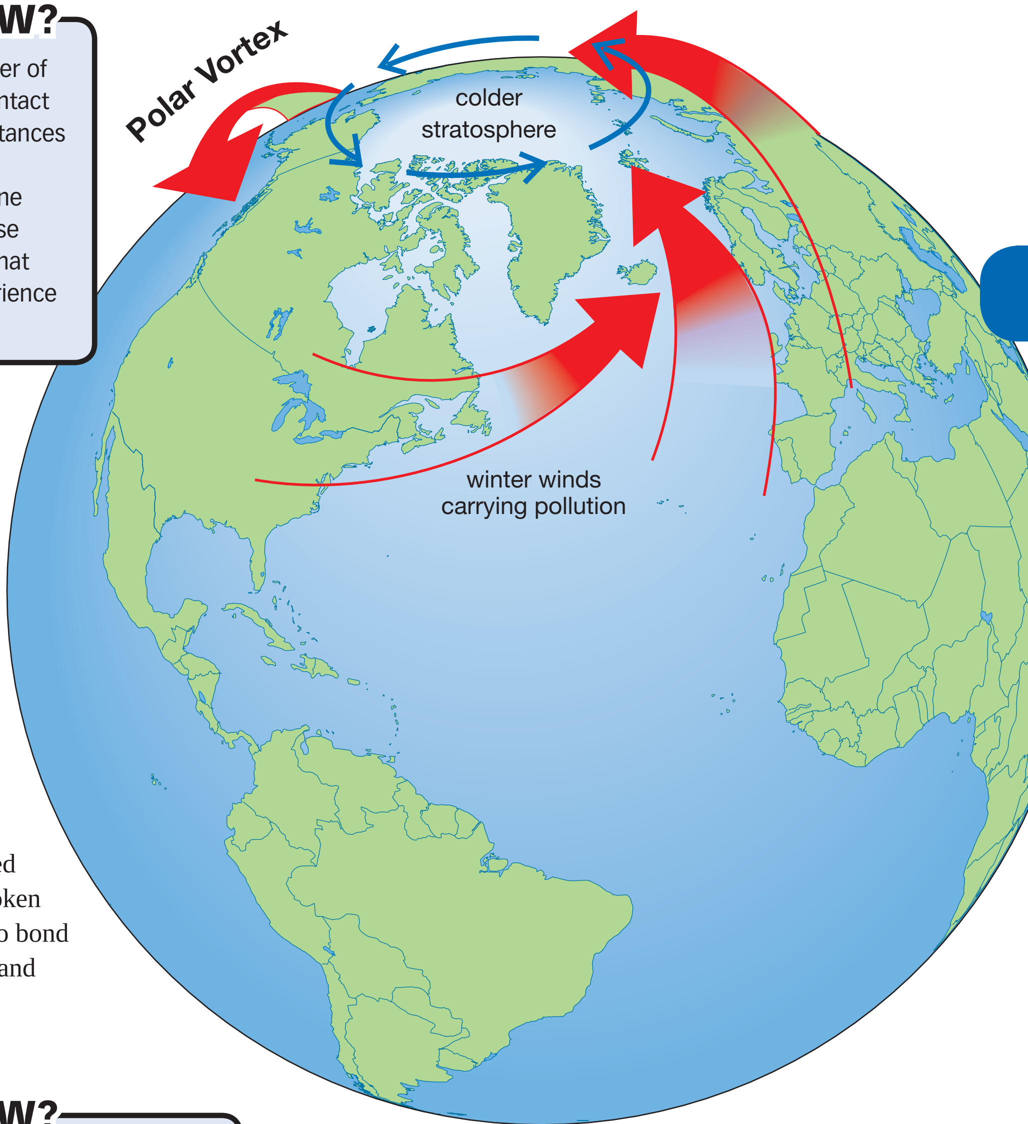
DID YOU KNOW?

Because of the large number of chemical substances you come in contact with, it is difficult to identify the substances that can present the greatest risk. Epidemiology is the branch of medicine that looks at the occurrence of disease and attempts to identify similarities that may exist between people that experience certain forms of disease.

Many herbicides and pesticides contain halogen atoms. As a result, concern exists regarding the effect pesticides can have on human health. When you eat, can you be sure your food doesn't contain traces of pesticides or herbicides that may have been used in its production?

Apart from environmental persistence, halogenated hydrocarbons are a health concern because they target important parts of the body: the central nervous system, heart, liver, and kidneys. As you learned earlier, chlorine compounds can be broken down. Chlorine radicals are also able to bond to organic compounds in these tissues and cause damage.

Focus on the Poles



DID YOU KNOW?

Alberta's Swan Hills Hazardous Waste Treatment Facility uses temperatures of 1200°C or higher to combust and break down the highly stable benzene ring in aromatic compounds. This facility is one of few sites in Canada capable of treating CFCs and other halogenated hydrocarbons like PCBs.

Earlier in this lesson you learned that organic compounds, like CFCs and other halogenated hydrocarbons, are detected in the tissues of arctic animals. Halogenated hydrocarbons, as you have seen, are used by industry and agriculture at lower latitudes and can be transported by prevailing wind patterns toward the polar regions.

Like all winds, the polar vortex is produced by the unequal heating of air. The winds that create the polar vortex are located higher in the atmosphere than other wind currents. Conditions exist to create a vortex at both the North Pole and South Pole. It is believed that these winds have drawn pollutants from industrialized areas toward the poles.

The collection of these compounds in the atmosphere, along with the cold temperatures that occur during winter, create polar stratospheric clouds. Much of the research on the atmosphere in the Arctic and Antarctic focuses on the chemical reactions that occur within these clouds and how these reactions affect the ozone layer and other phenomena.

2.1 Summary

In this lesson you studied the uses of hydrocarbons—aromatic compounds and halogenated hydrocarbons—by society as well as the impact these uses have had on the environment. You examined the chemical properties of these classes of compounds and you learned how the composition influences these properties. You then saw how these substances can be transported by wind currents and can be involved in reactions in the atmosphere. Their transport may have greater consequences for all parts of Earth and even the stratospheric ozone layer.

2.1 Questions

Knowledge

1. Prepare a summary table showing the different types of organic compounds that were introduced in this lesson. Use the following headings: Group Name, Example, Important Structures/Atoms, and Environmental Concerns.

Applying Concepts

2. The Montreal Protocol defines the following classes of substances.

Abbreviation	Meaning	Atoms in Molecule
CFC	chlorofluorocarbon	Cl, F, and C
HCFC	hydrochlorofluorocarbon	H, Cl, F, and C
HBFC	hydrobromofluorocarbon	H, Br, F, and C
HFC	hydrofluorocarbon	H, F, and C
HC	hydrocarbon	H and C
PFC	perfluorocarbon	F and C
Halon	N/A	Br, Cl (in some), F, H (in some), and C

Provide two examples for each class of substances. For each example, draw a structural diagram, write its chemical formula, and determine its systematic name. (Your examples should differ in the number of carbon atoms.)

3. Describe the difference between CFCs and HCFCs.
4. Suggestions have been made to replace the use of CFCs and HCFCs with hydrocarbons, like butane, and other compounds, like ammonia. Identify risks associated with the use of these suggested alternatives.
5. Describe how the action of winds within the polar vortex could contribute to the reduction in ozone at the North Pole and South Pole.
6. 1,1,1,2,3,3,3-heptafluoropropane (FM-200) and 1,1,1,3,3,3-hexafluoropropane (HFC-236fa) are replacements for halogenated bromine compounds (Halons) used in fire extinguishers in aircraft.
   a. Draw the chemical structures for these two compounds.
   b. Identify properties of these compounds that would make them suitable alternatives to Halons.
7. Explain why free radicals are reactive substances.
8. Use the Internet to locate information and then prepare a table that lists the antioxidants identified in this lesson and the food sources that contain these substances.
9. Use the Internet to find five examples of naturally occurring and synthetic compounds that contain aromatic rings. Indicate their source or importance.
10. List concerns about aromatic compounds identified in this lesson. Explain how these concerns can be attributed to the chemical properties of the aromatic ring.